Ecosystem-based Management Should Include an Assessment of the Impacts of Pacific Salmon Escapements and Enhancement on the Juvenile Salmon that Rear in the Strait of Georgia

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Abstract

Fisheries management science attempts to determine the number of fish that can be removed from a population without serious impacts on the ability of the population to replenish itself. The impacts on associated species are not determined despite legislation in Canada that identifies a requirement to manage at the ecosystem level. We provide two examples of management decisions at the species level that could have important impacts on the survival of other juvenile salmon rearing in the Strait of Georgia. Such impacts would be expected to be most important during climate and ocean regimes that are characterized by reduced productivity in the ocean habitat of Pacific salmon. Thus, it is necessary to recognize that ecosystem based management needs to include both an assessment of the interactions of juvenile Pacific salmon in the common rearing area in the Strait of Georgia and an awareness of the marine productivity of the current climatic regime.

Introduction

The Strait of Georgia is possibly the most important marine ecosystem on Canada's Pacific coast. It is the main rearing area for juvenile Pacific salmon that historically have contributed up to approximately 40% of the total Pacific salmon catch. Juveniles of all species remain in the strait for periods ranging from a few weeks to about 5 months. It is during this period that their survival to adults is mostly determined. The factors that affect their survival are a function of predation and individual growth rates (Beamish and Mahnken 1999; Beamish and Mahnken 2001; Beamish *et al.* 2002). Mortality caused by predators is well known and commonly believed to be the major factor affecting marine survival (Parker 1968; Pearcy 1992). However, recently is has been shown that juvenile coho that do not grow to a larger size have a substantially higher mortality over the winter (Beamish *et al.* 2003).

In biology there is an accepted relationship between animal size and metabolic costs (Schmidt-Nielsen 1984; Calder 1984; Shuter and Post 1990). Smaller fish use more energy per unit weight than larger fish. This means that smaller fish do not survive periods of energy deficits during the winter as well as larger fish. Management actions that cause increased competition could in turn reduce growth. Reduced growth could then result in higher mortality. Factors that reduce growth, therefore, could profoundly affect the abundance of adult salmon.

In 1996, Canada passed legislation that created the Oceans Act. Imbedded in this act is a requirement that the management of fisheries move forward on ecosystem-based approaches. One of the summary points in the Ocean Act in 1996 requires that Canada ensures that "conservation, based on an ecosystem approach, is of fundamental importance to maintaining biological diversity and productivity in the marine environment." (Government of Canada 1996)

In our paper, we propose that it is necessary to assess the impacts of adding large numbers of juvenile Pacific salmon to the shared ocean habitat of all juvenile Pacific salmon in the Strait of Georgia. We provide two examples of traditional single species management approaches that should include an assessment of ecosystem impacts.

Background

Our first example relates to the large escapements of pink salmon that occurred in 2001 (Figure 1). Pink salmon are the most abundant of the Pacific salmon, and the Fraser River pink salmon accounts for more than 60% of the total Canadian catch. They virtually all spawn in odd numbered years with almost no adults returning in even numbered years. The juveniles enter the ocean in the spring following spawning (even numbered year) and the juveniles leave the Strait of Georgia throughout the summer. Adults return to the Fraser River the following year after one winter at sea. Total returns have ranged from approximately 2 million in 1961 to over 20 million in 1991 and 2001. However escapements in 2001 were especially large due to management actions to protect both Thompson River coho salmon and late-returning Fraser River sockeye salmon stocks. As a result, over 20 million pink salmon escaped to the Fraser River. This was the highest escapement on record. This increased escapement would be expected to produce increased numbers of juvenile pink salmon entering the Strait of Georgia in 2002.
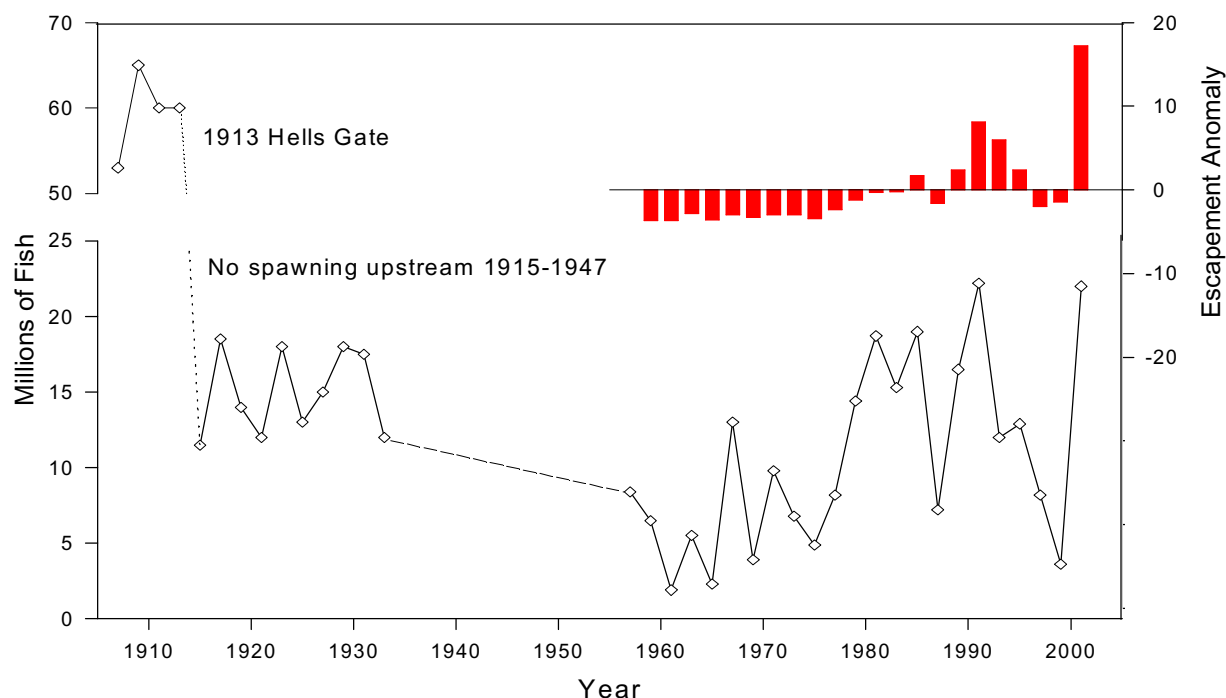
Figure 1. Pink salmon catch and escapement to the Fraser River. Catch and escapement numbers prior to 1957 are estimates calculated by W.E. Ricker (1958) and numbers from 1957 to 2001 are from the Pacific Salmon Commission. The escapement anomaly (1959-2001) shows the record high escapement of pink salmon in 2001.

Our second example relates to the large numbers of juvenile chum salmon that have been reared artificially and added to the Strait of Georgia. Historically chum salmon entered the strait in February to May and moved out of the strait in July (Healey 1980). However, in recent years juvenile chum have remained longer in the Strait of Georgia and this has been associated with increased numbers of juveniles entering the strait (Beamish and Folks 1998). The longer residence time for chum in the Strait of Georgia may also relate to climate changes, but the relevance is that more chum salmon feed for longer periods. Chum salmon have been produced by enhancement facilities around the Strait of Georgia since the mid 1950s although large scale enhancement began in the mid-1970s. Chum salmon are a relatively easy species for the enhancement program to propagate as they respond well to simple hatchery systems and are retained for only a few months prior to entering the ocean.

Methods

Surveys of juvenile salmon (ocean age 0) were conducted in the Strait of Georgia in July and September 1997 to 2002 as part of an ongoing juvenile salmon study. A surface trawl towed at approximately 5 knots was fished along fixed track lines throughout the Strait of Georgia. Specifics of the gear and survey design are outlined in Beamish and Folkes (1998) and Beamish *et al.* (2000a).

Juvenile salmon collected in the surveys were identified to species and counted. Fork lengths (nearest mm) and, when sea conditions permitted, weights (g) were recorded. Otoliths and scales were taken from a random sample of each set. Stomach contents of the fish that were sampled for otoliths were examined. Priority was given to the analysis of coho and chinook salmon, however, chum, pink and sockeye were also sampled. All stomach contents were examined on the vessel immediately after capture. The cardiac and phyloric portions of the stomach were removed and the volume of contents was estimated to the nearest 0.1cc. Contents were examined by eye and by 10x magnifying glass when necessary. Prey items were identified to the lowest taxonomic group possible. Taxonomic groups identified were recorded as percent of total volume. All identifications were conducted by the same person who is familiar with the identification of plankton in the Strait of Georgia.

For analysis of diet the contents were combined into major categories (Neville and Beamish 1999, King and Beamish 2000). Stomachs with volumes less than 0.1cc were considered empty and unidentifiable material was excluded from the analysis. For this paper only the 3 major diet categories for pink and chum salmon are included. The major diet categories from pink salmon collected in July of 1998, 2000, and 2002 are compared to coho and chinook salmon collected during the same period. The major diet items for chum salmon collected in September 1997 to 2000 are compared with coho salmon diets from the same period (updated from King and Beamish 2000).

Chum salmon releases from hatcheries on the Fraser River and river and streams entering the Strait of Georgia for both fed (fish that were fed prior to releases) and unfed fry were obtained from Fisheries and Oceans Canada Habitat Enhancement Branch (Roberta Cook, HEB Fisheries and Oceans Canada, personal communications). Data used in this paper include both fed and unfed fry. Data includes all production except for public involvement projects which release 5000 fry or less. Chum salmon abundance is compared between years using the average catch per unit effort (CPUE) in the salmon surveys. CPUE is the number of fish that would be caught in one hour (Beamish and Folkes 1998; Beamish *et al.* 2000a).

Temperature of the Strait of Georgia waters is measured at the Nanoose Bay Naval Underwater Weapons test Range located mid-way along the western side of the Strait of Georgia (Beamish *et al.* 1995). This series was used because it is the most complete series of vertical temperature in the strait, beginning in 1970 to the present with approximately 8-20 profiles per month. Data was averaged yearly for surface, 10m and near the bottom at about 395m.

Results

Juvenile pink salmon diet in the Strait of Georgia is similar to the diet of juvenile coho and chinook. The three key diet categories of pink salmon in the summer months of 1998, 2000 and 2002 were amphipods, decapods and euphausiids (Table 1). These three categories represented 79 to 87% volume of the pink salmon diets. These same categories represented 64 to 74% volume of the juvenile coho diets and 23 to 55% volume of the juvenile chinook diets. Coho and especially chinook salmon had teleost remains as a major component of their diet. Teleosts were minor, if present, in the pink diet.

Table 1. Primary diet categories of pink salmon in July 1998, 2000 and 2002 with comparison of diet categories for coho and chinook salmon. Note that the years are not consecutive as juvenile pink salmon are only abundant in even numbered years.

	Pink salmon			Coho salmon			Chinook salmon		
		2000	2002	1998	2000	2002	1998	2000	2002
Amphipods	40%	44%	56%	10%	11%	18%	8%	18%	16%
Decapods	20%	35%	14%	46%	54%	38%	5%	20%	18%
Euphausiids	19%	5%	17%	8%	5%	18%	10%	5%	21%
Total % of 3 categories	79%	84%	87%	64%	70%	74%	23%	43%	55%

The three primary diet items of chum salmon in September were amphipods, euphausiids and ctenephores (Table 2). Amphipods and euphausiids were also key categories for coho salmon with ctenephores seldom being a component of the diet. Teleosts represented 4.2 to 57.3% of the coho diet but only represented up to 3% of the chum diet. Amphipods and euphausiids represented over 60% of the chum diets in 1997 and 1998, however, 8.3%, 35.7% and 46.1 in 1999, 2000 and 2001 respectively. In these latter years, ctenephores were the major diet item (Table 2). Amphipods and euphausiids represented over 50% of the coho diets in 1998, 2000 and 2001. In 1997 and 1999 they comprised 35.4% and 38.1% respectively with teleosts representing up to 57% of their diet. Of the two diet categories that were consumed by both coho and chinook, amphipods were preferred in all years by chum salmon however coho salmon switched preferences between years (Table 2).
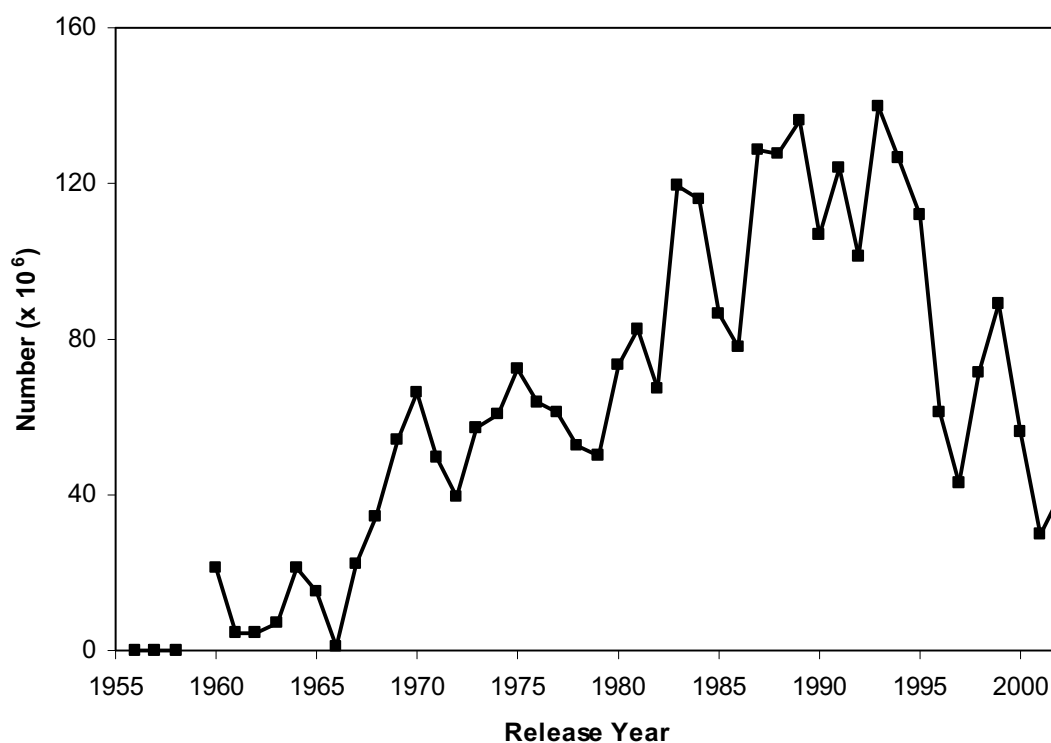
Figure 2. Releases of chum salmon fed and unfed fry from hatcheries around the Strait of Georgia basin. Data from Habitat Enhancement Branch, Department of Fisheries and Oceans Canada.

Table 2. Primary diet categories of chum and coho salmon in September 1997-2001.

		1997	1998	1999	2000	2001
Amphipods	Chum	58.4	34.7	5.1	25.3	31.1
	Coho	27.9	18.9	33.9	39.0	22.6
Euphausiids	Chum	10.4	25.6	3.2	10.4	13.0
	Coho	7.8	76.5	4.2	16.4	53.7
Ctenephores	Chum	28.2	28.0	84.6	46.4	34.0
Total % of 3 categories	Chum	97.0	88.3	92.9	82.1	75.1
	Coho	35.7	95.4	38.1	55.4	76.3

Hatchery production of chum salmon entering the Strait of Georgia increased from approximately 4 million in the early 1960s to a high of 140 million in 1993 (release year) (Figure 2). The average releases for the period 1987 to 1995 were 123 million. Since 1995 releases have decreased to the current level of 30 to 40 million. The CPUE of chum salmon in the Strait of Georgia in September averaged 77.0 for the years 1997 to 2001 and declined in 2002 to 23.7 (Table 3). This catch was greater than coho in all years (Table 3).

Table 3. Catch per unit effort of chum and coho salmon in September 1997 to 2002 in the Strait of Georgia.

	Chum salmon	Coho salmon
1997	70.8	31.4
1998	79.4	31.9
1999	77.4	48.0
2000	81.4	29.5
2001	77.2	40.0
2002	23.7	16.7
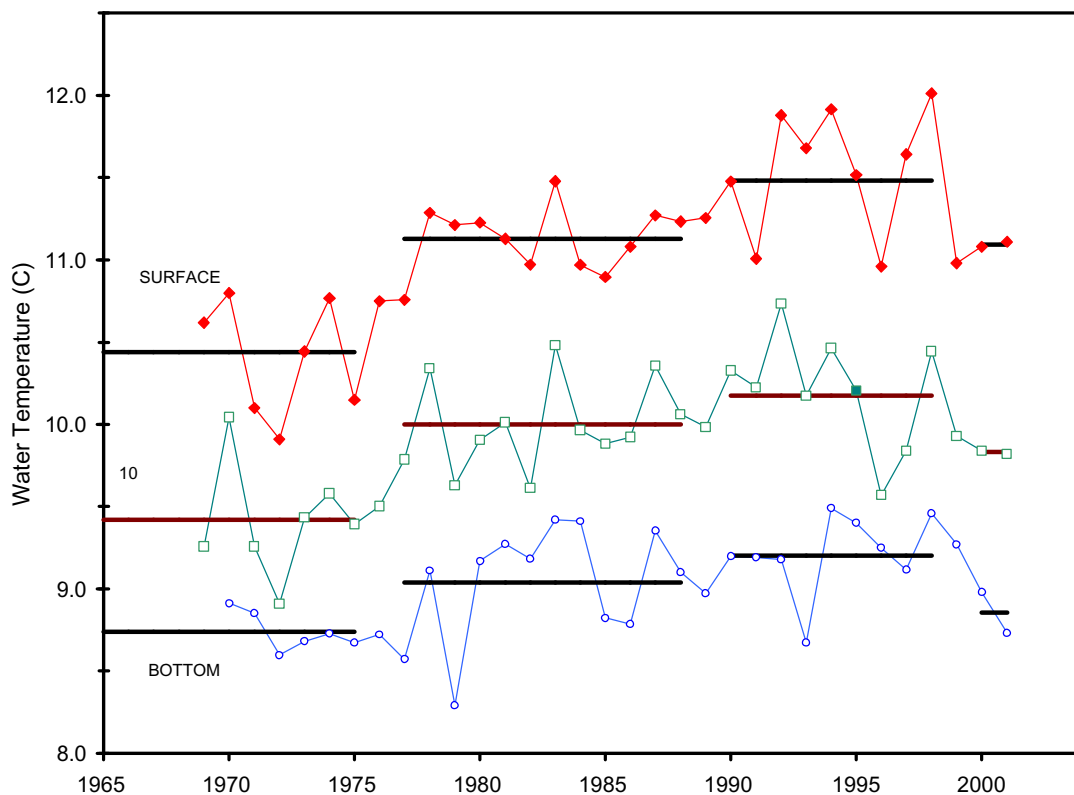
Figure 3. Average yearly temperatures at surface, 10m and bottom waters (395m). Straight lines are averages for 1965 to 1977, 1978 to 1989, 1990 to 1998 and 2000 to 2001. These are the regimes that have been shown to match with large-scale climate and ocean indicators (Benson and Trites, 2002, Beamish *et al.* 2000b).

Strait of Georgia water temperature as measured at the Nanoose Bay Naval Underwater Weapons Test Range is one example of the changes within the Strait of Georgia associated with regime changes. There are abrupt increases in the temperature in the strait in 1978 and 1990 (Beamish *et al.* 1995; Beamish *et al.* 2001b). There is a decrease in water temperature associated with the 1998 regime shift although the level of decrease remains uncertain with only a few years of data available (Figure 3). This decreased water temperature associated with the 1998 regime change also resulted in increased production within the Strait of Georgia including a doubling of the euphausiid biomass (Beamish *et al.* 2001c). However, 2002 was a year of reduced productivity within this regime (Sweeting and Beamish 2002). In 2002 the juvenile salmon CPUE declined and the individual salmon were smaller.

Discussion
We provided two examples of management decisions that resulted in large numbers of juvenile salmon entering the common feeding area in the Strait of Georgia. Our first example relates to a decision to allow an escapement of pink salmon that was the largest in history. The large escapement resulted from a concern that fishing could cause an incidental catch of salmon from other stocks that had been identified as requiring protection. However, the offspring from the escaped pink salmon entered the Strait of Georgia in 2002 and most certainly competed for food with the offspring of the stocks that were being protected. Diet analysis from the summer months of 3 pink years indicated that an overlap with coho and chinook diets did occur. Also of importance is that this competition occurred in 2002 at a time when there was a natural decline in the productivity of the Strait of Georgia (Sweeting and Beamish 2002).

Our second example involves large numbers of chum salmon were reared in hatcheries and released into the Strait of Georgia. King and Beamish (2000) showed an overlap between the diets of coho and chum salmon in September of 1997 and 1998. Our updated studies showed that there was an overlap in 2000 and 2001 although the key diet items represented a smaller component of the total diet and there was increased variability in the diet. There was little overlap in September 1999 with chum salmon consuming ctenephores almost exclusively. This increased variability occurred during a period of regime change and changes in the ocean productivity along with changes in relative abundance of other salmon species might alter the degree of diet overlap and competition in different seasons and years.

Pacific salmon species were also reared in hatcheries and released into the Strait of Georgia, further adding to the competition for prey. The assumption has been that the capacity of the Strait of Georgia to feed these juvenile salmon was adequate, although there is no scientific evidence that this assumption was researched. We propose that a management that is ecosystem based needs to understand how the additions of one species of juvenile Pacific salmon affects the survival of the other juvenile Pacific salmon that are added from hatcheries and from naturally spawning stocks as all these juveniles share a common feeding area. Thus it is possible that competition for food during periods of reduced ocean production, contributes to decreased growth and thereby to increased mortality during the first marine winter. Adding more juveniles to the ocean during periods of reduced ocean capacity to support them theoretically may actually reduce the numbers of adults.

Our studies of the factors that regulate the marine survival of Pacific salmon indicated that growth during the summer is linked to marine survival over the winter (Beamish and Mahnken 2001; Beamish *et al.* 2003). Smaller coho salmon had a significantly higher mortality over the fall and winter than larger coho salmon. We propose that these observations for coho probably apply to other juvenile Pacific salmon and smaller fish, in general, are less likely to survive these periods of energy deficit than larger fish. We have also shown that the amount of prey available to juvenile salmon in the Strait of Georgia is related to the particular climate and ocean regime (Beamish *et al.* 2001c; Beamish *et al.* 2002). The biomass of euphausiids in the Strait of Georgia doubled in 2000 after the climate regime shift in mid-1998. We proposed that the doubling of euphausiids was an indication that other prey abundances also increased. This means prey abundances prior to 2000 would be lower and perhaps limiting in relation to the ability of many juvenile Pacific salmon to grow to a size that would allow them to survive the first marine winter.

In this study, the impacts of our two examples are still being researched. Part of the complexity is that the impacts will vary among regimes. There could be very little impact if there was capacity within the ecosystem to support more fish or there could be substantial impact if there was reduced carrying capacity and growth or behaviour or both was affected. Our message is that Canada has legislation that requires that we understand the impacts of adding more juvenile salmon to the marine habitat in the Strait of Georgia and not simply assume that the ecosystem will look after itself.

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